Field Test of the Puma™ AE (All Environment) Small Unmanned Aircraft System (UAS): September 14-16, 2014

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Abstract

Traditional methods for marine mammal, seabird and turtle observations require qualified observers aboard ships or aircraft. These methods are cost-prohibitive for National Marine Sanctuaries to conduct at regular intervals. The Monterey Bay National Marine Sanctuary used a NOAA-owned Puma™ AE (All Environment) small unmanned aircraft system (UAS) to field-test its capability to detect various targets on the ocean's surface, including marine mammals and other large marine organisms. The Puma UAS is a waterproof, all-electric propeller powered aircraft that is light enough to be launched by hand from small vessels, and includes a gimbaled camera payload that can swivel 360 degrees with zoom and infrared capabilities. Over two days, four flights totaling a length of 206.7 kilometers were made in northern Monterey Bay. Although primary targets (leatherback turtles and their jellyfish prey) were never observed, a total of eight Humpback whales (*Megaptera novaeangliae*) and one ocean sunfish (*Mola mola)* were recorded during six total hours of flight. The UAS proved adequate in detecting objects as small as one meter across from altitudes as low as 60 meters and large animals, such as whales at its maximum flight altitude of 300 meters. Although this system requires less personnel and costs significantly less than traditional observation methods, it lacks a high-definition camera, and may not yet be suited for rigorous data collection due to inability to calculate total area covered (i.e., target densities unobtainable). In its current configuration, this system may be better suited for reconnaissance applications within National Marine Sanctuaries, although future configurations of the UAS could remedy its current deficiencies.

Introduction

Marine mammal, marine turtle, and seabird observations are traditionally made by qualified observers from ships and aircraft. These observations help scientists and resource managers estimate the population of these species within the part of the ocean observed. However, these missions can be cost-prohibitive with the expense of the vessel(s) and paid qualified and experienced observers. As a potentially lower-cost alternative, the West Coast Region of the Office of National Marine Sanctuaries (ONMS) wanted to assess the capability of the Puma™ AE (All Environment) small unmanned aircraft system (UAS) (*Appendix A*) to detect and count leatherback turtles, jellyfish, and marine mammals in northern Monterey Bay. Additionally, exploration of new field tools may enhance both the research capabilities and resource protection of the ONMS and produce outreach materials in the form of video and project information available on the web.

Methods

Personnel for this project included two pilots from the Office of Marine and Aviation Operations (OMAO), an FAA-qualified observer, a vessel captain and mate, the principal investigator, and additional observers, if there was adequate room on the vessel. Field operations occurred on September 14 and 15, 2014, but were scrubbed on the planned third day (September 16) due to an oil leak on the Sanctuary vessel. The FAA cleared operations to occur anywhere within northern Monterey Bay and up to Point Año Nuevo. Operations never came within one mile of the shoreline.

The Puma UAS is an all-environment and fully waterproof aircraft system, has a wing span of 2.8 meters, a length of 1.4 meters, and weighs 6.1 kg. An enhanced precision navigation system with secondary GPS provides great positional accuracy and reliability. The Puma's electric motor powers a propeller in the nose of the plane and was launched by hand by one of the pilots off the deck of the R4107 (Figure 1). The Puma is capable of flying to an altitude of 10,000 feet and has a 15 kilometer range, but due to FAA regulations, it was limited to a 1,000 foot ceiling and a radius of 1.6 km around the vessel for the duration of this project. The drone flies at a speed between 20 to 45 knots (37 to 83 km/hr). The gimbaled camera is capable of 360 degree continuous pan, +10 to -90 tilt, and includes an infrared camera.

Figure 1. ***Left*****: R4107, a 41 foot Class III boat operated by the West Coast Region of the Office of National Marine Sanctuaries.** ***Right*****: Puma drone pictured moments after the OMAO pilot launched it by hand of the back deck of the R4107.**

Flight was controlled via waypoints entered into a laptop computer operated by one of the pilots (Figure 2). During flight, the second pilot viewed live video in a shaded monitor and controlled the pan, tilt and zoom of the camera system (Figure 3). A 7-inch screen displayed live video to the principal investigator and observer(s) (Figure 4).

Figure 2. A pilot monitors the live position of the Puma on a map. With a stylus, the pilot can enter up to four manual waypoints, control altitude, and can program the drone to circle a specific coordinate, such as an animal or object in the ocean.

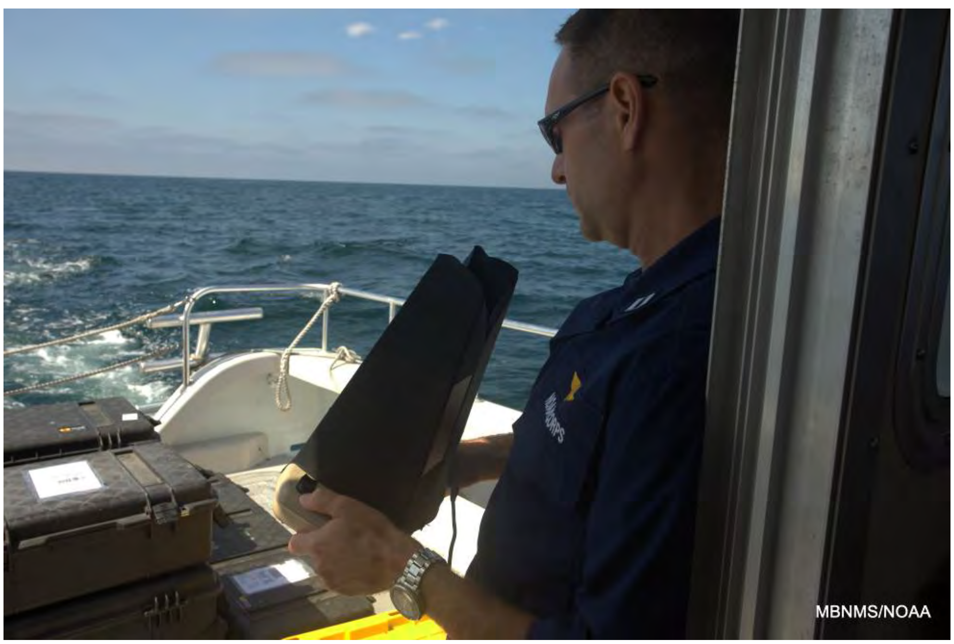


Figure 3. An OMAO pilot views the live video feed from the UAS on a small tablet covered by a hood (for increased visibility). The tablet also houses controls for the gimbaled video camera.

Figure 4. The principal investigator and observer(s) viewed the live video on a 7 inch tablet. Additional wiring was available for connection to larger monitors.

A rigid transect method was not adhered to, as this was a pilot project. However, an attempt was made to run the R4107 in a predetermined heading within the operational area of northern Monterey Bay. After launch, the Puma would follow the R4107 and fly an alternating “snake” pattern that was roughly perpendicular to the bearing of the R4107. Each perpendicular segment ranged between 1 and 1.3 kilometers wide; never more than 0.7 kilometers from the vessel, well within FAA regulations (Figure 5).

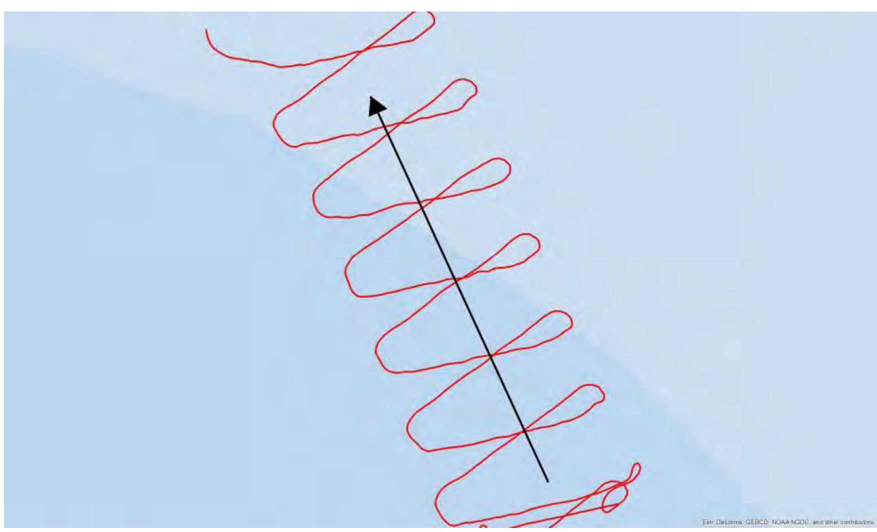


Figure 5. The black arrow represents the direction of the R4107 and the red line represents an actual flight trackline of the UAS drone as it flew just behind the vessel. These flight lines are approximately 1.3 km wide.

When objects of interest were noted by the pilot or observer, the pilot controlling the video camera would attempt to zoom in on the object to attempt identification. If the object deserved further reconnaissance, the drone was programmed to circle the object. Identified targets were recorded onto a data sheet. To explore the camera's capability of identifying objects at different altitudes, flight altitudes ranged between 60 and 300 meters, although the majority of time was spent near 60 meters. All video (standard definition) was recorded to a laptop hard drive and are available for future review. At the conclusion of the flight, the pilot gently landed the drone into the water, where it was retrieved from the back deck by the pilots (Figure 6).

Figure 6. Upper left: Drone moments before "splash down;" gently landing in the water; Upper right: The moment of landing; Lower left: the drone is completely waterproof and buoyant; Lower right: An OMAO pilot retrieves the drone from the back deck of the R4107.

Results

Four flights were made over two days (two each day) and totaled 260.7 kilometers in length. Total area covered could not be calculated as various altitudes were flown throughout the four flights, and the width of the image varies at different camera zoom levels. No leatherback turtles or jellies were observed, but a total of eight humpback whales (*Megaptera novaeangliae*) and one ocean sunfish (*Mola mola)* were observed (Table 1 and Figure 7).

Table 1. Length of each flight (km) and animals observed.

Date	Flight #	Length (km)	Humpback Whales	*Mola mola*
09/14/14	1	79.3	3	0
09/14/14	2	25.1	0	0
09/15/14	1	96.3	0	0
09/15/14	2	60	5	1
Total	**4**	**260.7**	**8**	**1**

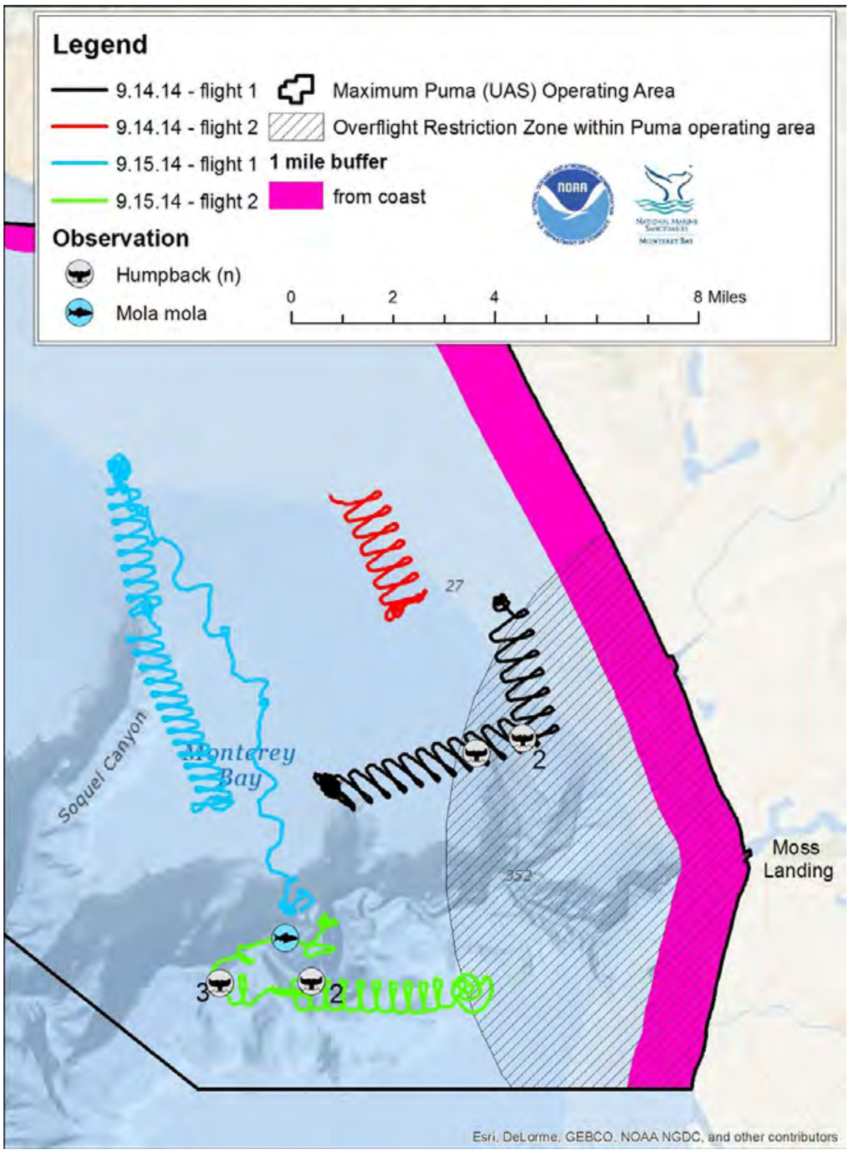


Figure 7. Map of all four tracklines flown and animal observations within the FAA-cleared operational area in northern Monterey Bay.

Humpback whales were easily identifiable by the Puma, even at altitudes of 300 meters (Figure 8). Smaller objects such as small buoys (Figure 9) and a *Mola mola* (Figure 10) were still easily recognized at lower altitudes of 60 to 80 meters. Additional objects noted (but not systematically recorded) included kelp wrack (*Macrocystis pyrifera*), buoys (e.g. crab pots), and unidentifiable seabirds. Although other marine mammals (*Grampus griseus* and *Lagenorhynchus obliquidens*) were encountered during transit on the R4107, none were observed directly from the Puma.

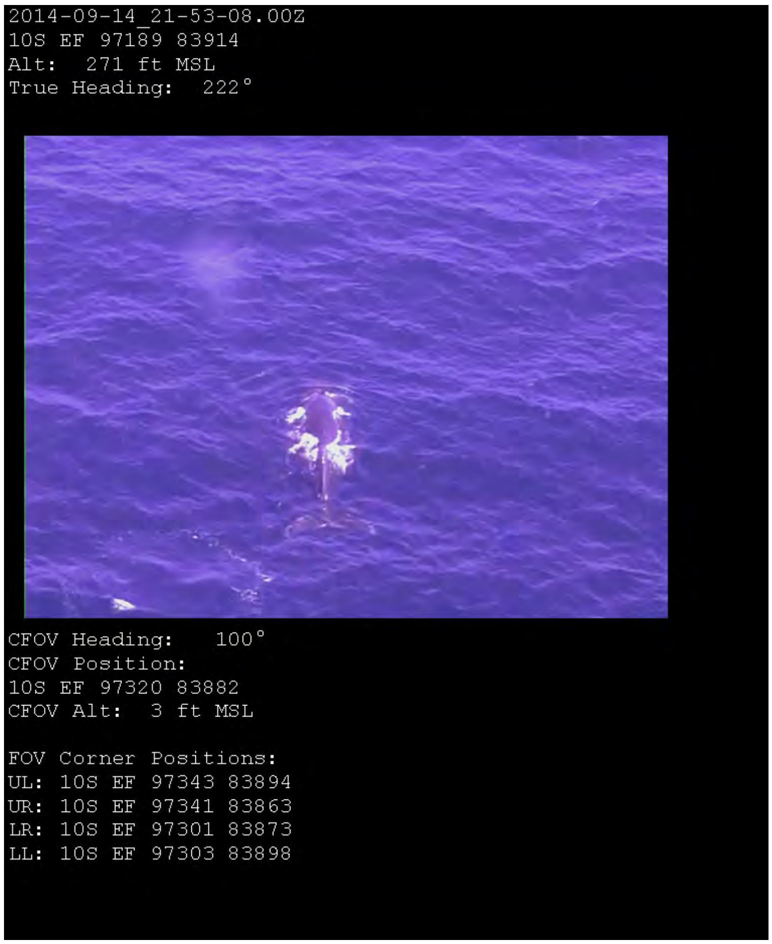


Figure 8. A humpack whale (*Megaptera novaeangliae*) as observed from the Puma UAS at an altitude of 271 feet (83 meters).

Figure 9. During flight one, a small buoy (pictured on left) was thrown from the R4107 (pictured on right) to initially test the gimbaled camera system aboard the UAS.

Figure 10. A *Mola mola* as pictured from an altitude of 60 meters in a video frame grab from the Puma UAS.

Discussion

The Puma UAS is primarily a reconnaissance tool for U.S. military applications. This particular system, now owned by NOAA, comes from the military and is optimized for scouting for targets and potential hazards in war zones. Along this same vein, this system could be optimal for scouting for illegal activity in the ocean such as illegal dumping, fishing in no-take marine protected areas, and even drug trafficking. This was the first time this system was applied to marine mammal observations within a National Marine Sanctuary, and furthermore, was the first time this system was used to run stratified “transects” to systematically cover an area with traditional field ecology methods.

Advantages to this system are its ability to be deployed with minimal crew and on small platforms such as the R4107 or even smaller vessels such as inflatables. The cost of an operational day is less than half of traditional plane-based marine mammal observation protocols (Table 2). The ability for the drone to circle and further investigate targets at lower altitudes than manned aircraft may enhance identification of single targets over traditional methods.

Table 2. Estimated costs (aerial platform costs based on FY 13 OMAO budget costs for internal NOAA users) for aerial and ship platforms that have conducted marine mammal and seabird observations within MBNMS. *The UAS PUMA requires a ship platform, so that additional costs must be considered. The R/V *Shimada* is a 208 foot vessel capable of multi-week long trips, multi-discipline science projects, and 24 hour operations.

Aerial Platform	**Cost per 12 hour day**	**Comments**
Twin Otter	$7,394 - $9,244	does not include salary for observers
UAS - PUMA*	$1,617	For six, 90 minute flights
Ship Platform		
R/V *Fulmar*	$3,000	Equipped for multi-day trips
R4107	$1,600	Restricted to day trips
R/V *Shimada*	$20,000	Estimated daily cost

Disadvantages to this system include the inability to calculate the width of a fixed camera view and thus densities of objects cannot be calculated, unlike traditional methods. Although a future version of this drone may include a high-definition camera, this current system is only capable of standard definition, making identification of some targets a challenge, especially over human eye-sight from a plane (enhanced with binoculars). Due to the limitations of the Puma UAS, it is less suited for rigorous data collection and is not comparable to traditional survey methods.

When considering cost per linear distance surveyed, the UAS comes out at about half the cost of the Twin Otter (Table 3). On January 10, 2010, the Twin Otter flew to the Davidson Seamount and recorded 550 km of survey data. This represents a conservative estimate on what the twin otter can cover in a day, since the plane had to fly 70 nautical miles each way from Monterey Airport to the Davidson Seamount. Although the maximum field of view angle for the UAS is similar to that of an observer's on the Twin Otter (15.75° to 12°, respectively), the observer has a high confidence of a correct identification at the limits of their field of view. The edge of the drone's maximum field of view is further distorted due to distance, and can be subject to sun angle, swell and wind chop that the camera's sensor has a difficult time resolving without visual noise. These reasons presumably mean the Twin Otter covers significantly more area at a higher target identification confidence level than the drone. The Twin Otter has a reliably wide 2 kilometer observer footprint. In a real-world application, these costs may be closer when considering cost per unit area surveyed.

Table 4. Estimated cost per linear distance (km) by platform for a 12 hour day of marine mammal observations. Estimated cost per day sources: OMAO and MBNMS. UAS-PUMA minimum linear distance determined by the 65 km average flight distance from the four flights during this project, multiplied by a maximum of six surveys in one day. Distances for R/V *Fulmar* and *Shimada* are based on a survey speed of 10 knots (18.5 km/hr) for 12 hours. Large vessels, such as the R/V *Shimada,* require a workboat to be launched with personnel to retrieve the drone once it lands in the water.

Platform	**Min linear distance (km)**	**Cost/day**	**Cost/linear km**
Twin Otter*	550	$ 9,244.00	$ 16.81
UAS - PUMA (4)	390	$ 3,217.00	$ 8.25
UAS - PUMA (F)	390	$ 4,617.00	$ 11.84
R/V *Fulmar*	222	$ 3,000.00	$ 13.51
R/V *Shimada*	222	$ 20,000.00	$ 90.09

* Maximum daily cost. Does not include salary for observers.

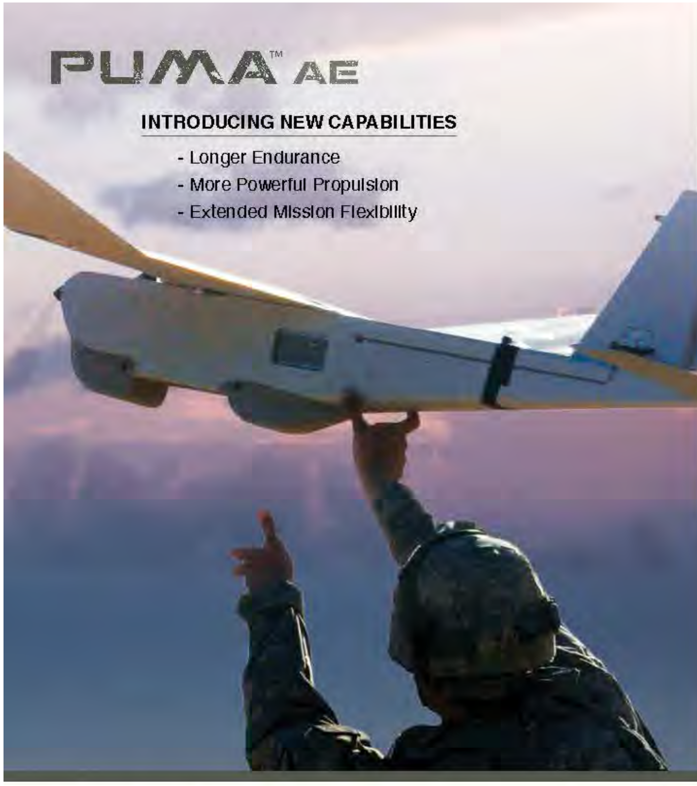
(4) - when using R4107

(F) - when using R/V Fulmar

Regarding application to National Marine Sanctuary interests, in its current configuration, the Puma UAS could be optimally used to detect illegal activity or perhaps for reconnaissance purposes such as finding an entangled whale that may have previously been reported by other transiting vessels. However, these applications would have to be conformed to current FAA regulations, as they limit the range of the drone to a 1.6 kilometer radius from the operational base or vessel.

Future enhancements to the Puma UAS may include high-definition cameras and software that can calculate area covered. These hardware and software developments will greatly increase the drone's application to more traditional and comparable quantitative survey methodology.

Appendix A



Overview

Puma AE (All Environment) is a fully waterproof, small, unmanned aircraft system (UAS) designed for land and maritime operations. Capable of landing in water or on land, the Puma AE empowers the operator with an operational flexibility never before available in the small UAS class.

The Puma AE delivers 3.5+ hours of flight endurance with versatile smart batteries options to support diverse mission requirements. Its powerful propulsion system and aerodynamic design make it efficient and easy to launch especially in high altitudes and hotter climates. Puma AE carries a gimbaled payload with an electro-optical (EO) and infrared (IR) cameras. For increased payload capacity, an optional under wing Transit Bay is available, plus a plug and play secondary power adapter is incorporated for increased mission flexibility.

The enhanced precision navigation system with secondary GPS provides greater positional accuracy and reliability of the Puma AE. AV's common ground control system allows the operator to control the aircraft manually or program it for GPS-based autonomous navigation.

Key Features

- **All Environment - Fully Waterproof**
- **3.5+ Hour Flight Endurance**
- **Smart Battery options to support diverse missions**
- **Gimbaled EO & IR Payload**
- **Increased Payload Capacity with optional under wing Transit Bay**
- **Powerful and Efficient Propulsion System**
- **Precision Navigation System with Secondary GPS**
- **Plug and Play Secondary Power Adapter**
- **Reinforced Fuselage for Improved Durability**

Specifications

Payloads	Gimbaled payload, 360 degree continuous pan, +10 to -90 degrees tilt, stabilized EO, IR camera, and IR Illuminator all in one modular payload
Range	15 km
Endurance	3.5+ hours
Speed	37-83 km/h, 20 to 45 knots
Operating Altitude (Typ.)	500 ft (152 m) AGL
Wing Span	9.2 ft (2.8 m)
Length	4.6 ft (1.4 m)
Weight	13.5 lbs (6.1 kg)
GCS	Common GCS with Raven, Wasp and Shrike
Launch Method	Hand-launched, rail launch (optional)
Recovery Method	Autonomous or manual deep-stall landing

www.avinc.com/puma

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Acknowledgements

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You may find updates to this project and future projects that use this and/or other unmanned aircraft at http://sanctuarysimon.org/projects/100420.